Long wave measurements at bay-shaped coasts using a pressure gauge (II)-Mano and Ryotsu bays

Kuniaki ABE

Niigata Junior College, The Nippon Dental University Hamauracho 1-8, Niigata City, 951-8580, Japan

(Received 29 November 2002; published 20 March 2003)

Abstract

Long wave measurements were conducted at Mano and Ryotsu bays in Sado Island, Hosyu, Japan. A pressure gauge was set in the sea at coasts of the heads and water levels were detected for 6 hours with time interval of 1 minute on August 22-24, 2002. The measurements were repeated four times for each station. They were decomposed into the amplitude spectra. As the result periods of 44-49 and 13,14,22,54 minutes predominated at Mano and Ryotsu bays, respectively. It is demonstrated from numerical simulations assuming a sinusoidal incidence that the fundamental modes are 42 and 24 minutes for Mano and Ryotsu bays, respectively. Thus, it is concluded that predominant periods of 47 and 22 minutes observed at Mano and Ryotsu bays are interpreted as the fundamental modes. The predominant period of 22 minutes at Ryotsu bay is supported from the same spectral peak observed at Ryotsu tide station, last year and also supported from an average recurrence time of 21 minutes at the 1964 Niigata earthquake tsunami in Ryotsu bay.

Key Index Words: *Long wave measurement, pressure guage*, Mano bay, Ryotsu bay.

Introduction

Omori (1900) found a regular oscillation with the same period of 7-8 minutes in three tsunamis observed at Ayukawa tide station, Japan, which is located nearest to head of the bay. This fact led him to liquid pendulum hypothesis of tsunami. Thereafter, Kato et al. (1961) observed characteristic response of the 1960 Chile tsunami to bays different from that of the 1933 Sanriku tsunami. Namely they explained the difference as resonance of bay to tsunami with a different period. Moreover, Nakamura and Watanabe (1961) noticed forerunner of the 1960 Chile tsunami and interpreted it as multiply reflected wave of the initial motion. Recently, Abe (2002a) studied predominant periods of tsunamis observed at Ayukawa tide station using spectra for 35 tsunamis and described that a predominant period of 9 minutes is one of most frequently observed predominant periods in this bay.

Natural oscillation proper to a bay is called seiche, which has the source in an oscillation of lake. In a quiet sea Honda et al. (1908) carried out the observations using a portable pressure gage of mercury column. Takahashi (1934), Aida et al. (1972) also measured sea levels at some bays using their portable gages. Recently Abe (2002b) measured the sea level oscillation using a pressure gage of semiconductor, sold as a commercial product. These results, even if they are not enough to discuss the reproducibility, show that the natural oscillation is observed in a quiet sea.

There are two bays at Sado Island, Japan, in which the natural oscillation has not been measured. Honda et al. (1908) gave the periods of 44 and 22 minutes from calculations for Mano and Ryotsu bays, respectively. Nakagawa (1953) proposed a model of 16.5 minutes for Ryotsu bay. At the head of Ryotsu bay a tide station, managed by Niigata Prefecture, is operating and recorded two tsunamis of the 1983 Nihonkaichubu-oki earthquake and the 1993 Hokkaidonansei-oki earthquake. The bay head was invaded by the 1964 Niigata earthquake tsunami and the data of eyewitness introduced by Aida et al., (1964) showed a regular oscillation of 16-26 minutes (average 21 minutes) in the period. It is ready to measure the natural oscillation in a quiet sea at Ryotsu and Mano bays. Thus, it is possible to compare the observed spectra with those of the tsunamis.

Method

Pressure gauge used is the same as that used by Abe (2002). The frequency response is flat for tsunami frequency (Abe, 2001, 2002). From the result it is concluded that the long wave of 5 min and more is reproduced completely. Since the sensor is too light to stay at a point without flowing, it needs a weight in the water. Thus, it was fixed with a weight in the sea nearest to pier or breakwater at the head of bays. Sea level above the sensor was measured for 6 hours with time interval of 1 minute and stored in the memory. The data was taken out into a laboratory computer and decomposed into the spectra.

In the spectral computation some numerical filters are used. To reduce the tidal level and the end effect Hanning window is applied to time series of deviation from the average level. After applying the window the amplitude spectra are obtained using Goertzel method and the result is smoothed through a running average.

Observations

The pressure gauge was put in the sea at the heads of Mano and Ryotsu bays (see Figure 1). The measurements were carried out at Mano bay on 22-23 August 2002 and at Ryotsu bay on 23-24 August 2002. There was a rainfall from night on the 23rd day to morning on the 24th day but except the period it was fine and wind was weak. At Ryotsu bay on the 23rd day there was a small swell radiated from a low atmospheric pressure at east of Hokkaido, Japan. At the same place the measurements were repeated four times. Examples of observed sea level oscillations are shown in Figure 2. The figure shows that the maximum double amplitude reached 0.38 m at Ryotsu bay and 0.11 m at Mano bay. The amplitude spectra are shown in Figure 3 and Figure 4. We notice the most predominant period in the spectra. They are 13, 22,14 and 52 minutes at Ryotsu bay. Especially 13-14 and 22 minutes are noticeable in the amplitude. On the other hand they are 49,23,49 and 44 minutes at Mano bay. The spectral amplitude of 44-49 minutes is extremely large at Mano bay.

Tsunami spectra at Ryotsu bay

At Ryotsu tide station there are records of two tsunamis, the Nihonkaichubu-oki earthquake tsunami on 26 May 1983 and the Hokkaidonansei-oki earthquake tsunami on 12 July 1993. The station is also located at the head and 1.3 km south from the observation point as shown in Figure 1. The sea levels were read from the tide gauge records during the time of 6 hours from the earthquakes' origin time with the interval of 1 minute. The amplitude spectra were obtained by the same method as shown in the former paragraph and the spectra are shown in Figure 5. The result shows that amplitude of the 1983 tsunami was larger than that of the 1993 tsunami. As for the predominant period the most predominant period of 24 minutes at the 1983 tsunami was also observed at the 1993 tsunami. But the excitation was not so strong as that of the former one. At the 1993 tsunami predominant periods of 14 and 9 minutes were observed with that of 24 minutes. The spectral similarity between two tsunamis is not so high for all the frequency range. The appearance of the same predominant period of 24 minutes between the two suggests that both the tsunami included the component and it is a period of natural oscillation of this bay. On the other hand pre-

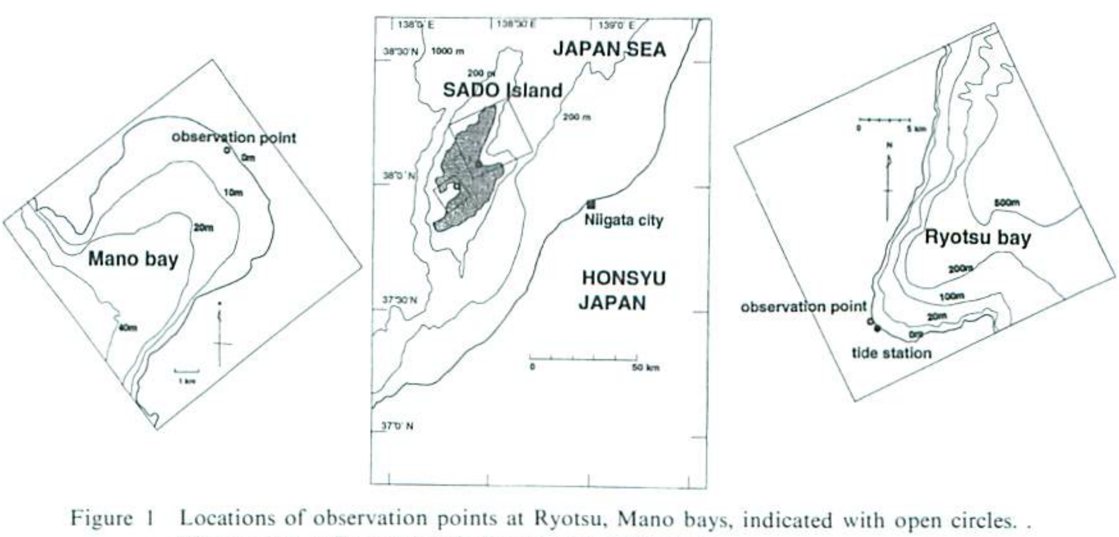

Figure 1 Locations of observation points at Ryotsu, Mano bays, indicated with open circles. . Tide station at Ryotsu bay is shown with solid circle

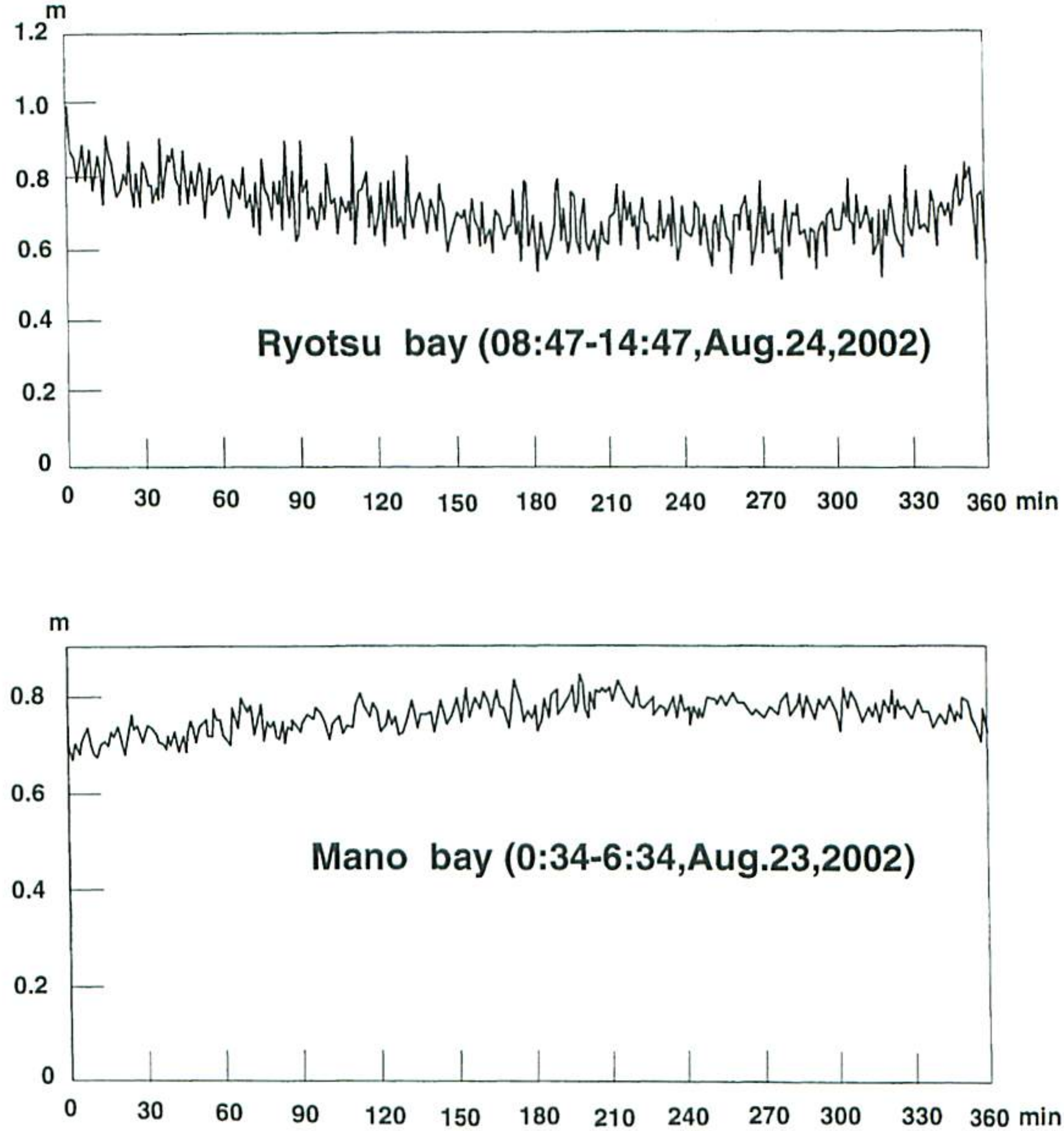

Figure 2 Examples of sea-levels observed at Ryotsu (top) and Mano (bottom) bays.

dominant periods of 15 and 9 minutes, not included in both the tsunamis, are possibly attributed to different source mechanism including a sea depth of the source. Generally speaking the former tsunami has a long component in comparison with that of the latter. One of the reasons is found in a sea depth of the source (~2000m) shallower than that of the latter (~3000m).

Response functions from the models

Problem of long-wave response at the observation points result in solving Helmholtz equation. The solution is numerically obtained applying finite element method (FEM) to bay's topography (e.g. Abe, 1986). Assuming a plane sinusoidal wave with any frequency incident to bay mouth, we can obtain amplitude at all the node points including the point nearest to the observation point. After repeating the computation with changing the frequency amplitude response is obtained as a function of frequency. Node map of the model, space distribution of the amplitude for the fundamental mode and the profile are shown in Figure 6 for Ryotsu and Mano bays. The amplitude responses, computed at the observation points using the models, are shown in Figure 7. The fundamental mode is found from a large

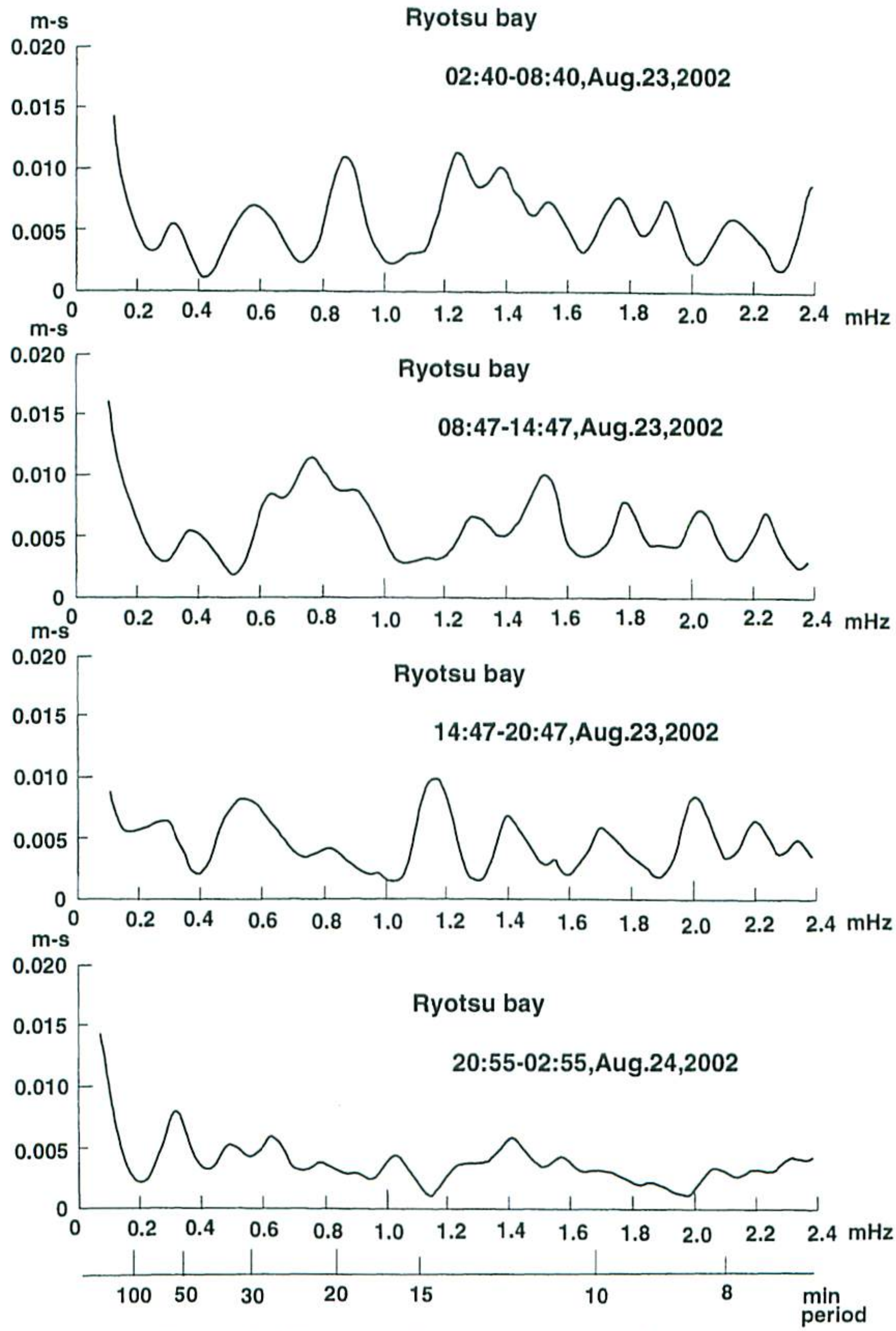

Figure 3 Amplitude spectra of the sea-levels obtained at Ryotsu bay.

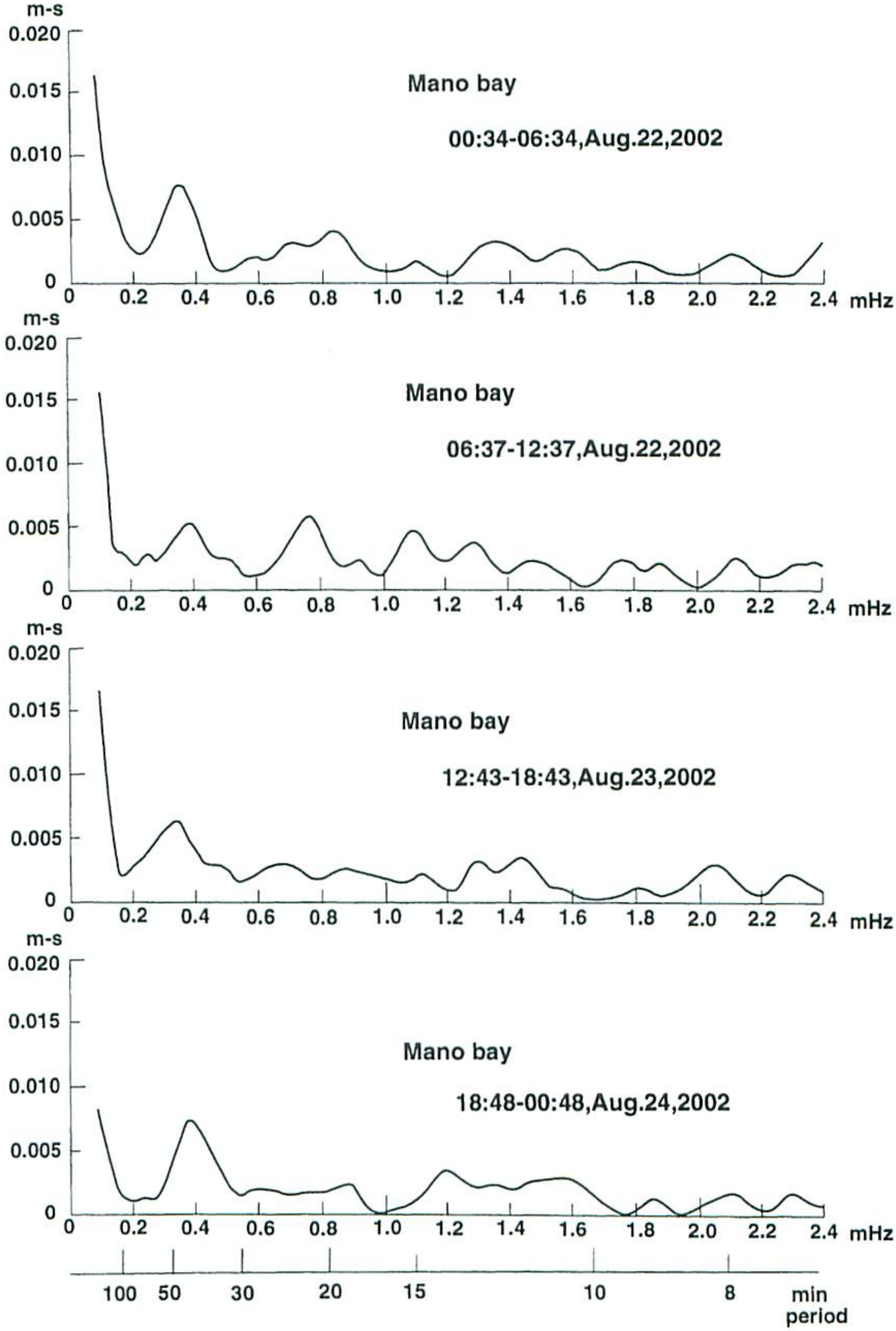

Figure 4 Amplitude spectra of the sea-levels obtained at Mano bay.

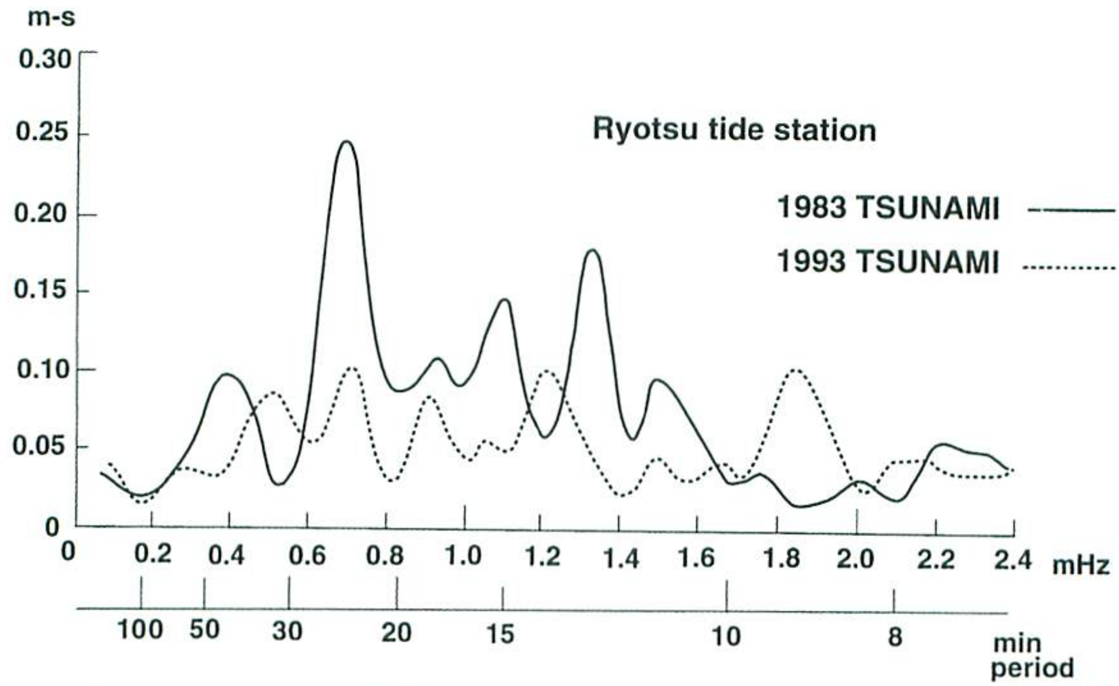

Figure 5 Amplitude spectra of the 1983 Nihonkai-chubu earthquake tsunami and the 1993 Hokkaido nansei-oki earthquake tsunami observed at Ryotsu tide station

amplitude of long period in phase with that of mouth. From the figure predominant period of 24 minutes is supported to be the fundamental mode at Ryotsu bay. Similarly the predominant period of 42 minutes is the fundamental mode of Mano bay. In comparison with the observed spectra we find good agreements of the spectral peaks with the large computed amplitudes for both the cases. The agreement is fairly good for Mano bay but is moderately good for Ryotsu bay. The maximum amplitude is found at shorter period component for Ryotsu bay. In the model a mouth-distance dependence was studied with changing the distance. Model 1,2 and 3 have mouth distances of 10.5, 18 and 23.5 km, respectively. For the three models amplitude responses were computed at the observation point and shown in Figure 8. As for the fundamental mode the period tends to be large with the distance. This result suggests a model dependence of the response. The periods of the fundamental mode 19,21 and 24 were obtained for model 1, 2 and 3, respectively. The observed predominant period of 22 minutes is adequately approximated from model 3, which was used in the first stage of this paragraph. In model 2 period of 21 minutes predominated but the wave profile brought a reversion of phase between mouth and head. Accordingly it is not a fundamental mode.

Spectra of tide gauge record in a quiet sea condition

A preliminary observation at Ryotsu bay in a quiet sea condition was carried out in the port on 23-25 August 2001. At that time tide gauge record observed at Ryotsu tide station was referred for the comparison and decomposed into the amplitude spectra. Among them a typical example is shown in Figure 9. The record definitely showed predominant period of 22 minutes. Since the period also predominated in other data set, it is concluded to be 22 minutes as a natural period.

Discussion

At Mano bay predominant period of 44-49 minutes was observed. In all the cases it appeared as the spectral peak. So it is stable but a little bit fluctuated. As the average it is 47 minutes. From a computation using the model a period of 42 minutes is verified as the fundamental mode of this bay. Since the difference is small, the observed period is approximated as that of the fundamental mode of this bay. The period of 44 minutes obtained from the average depth by Honda et al. (1908) is also approximation of the observed period of 47 minutes. The facts that the predominant period is stable and there is little other component than the predominant

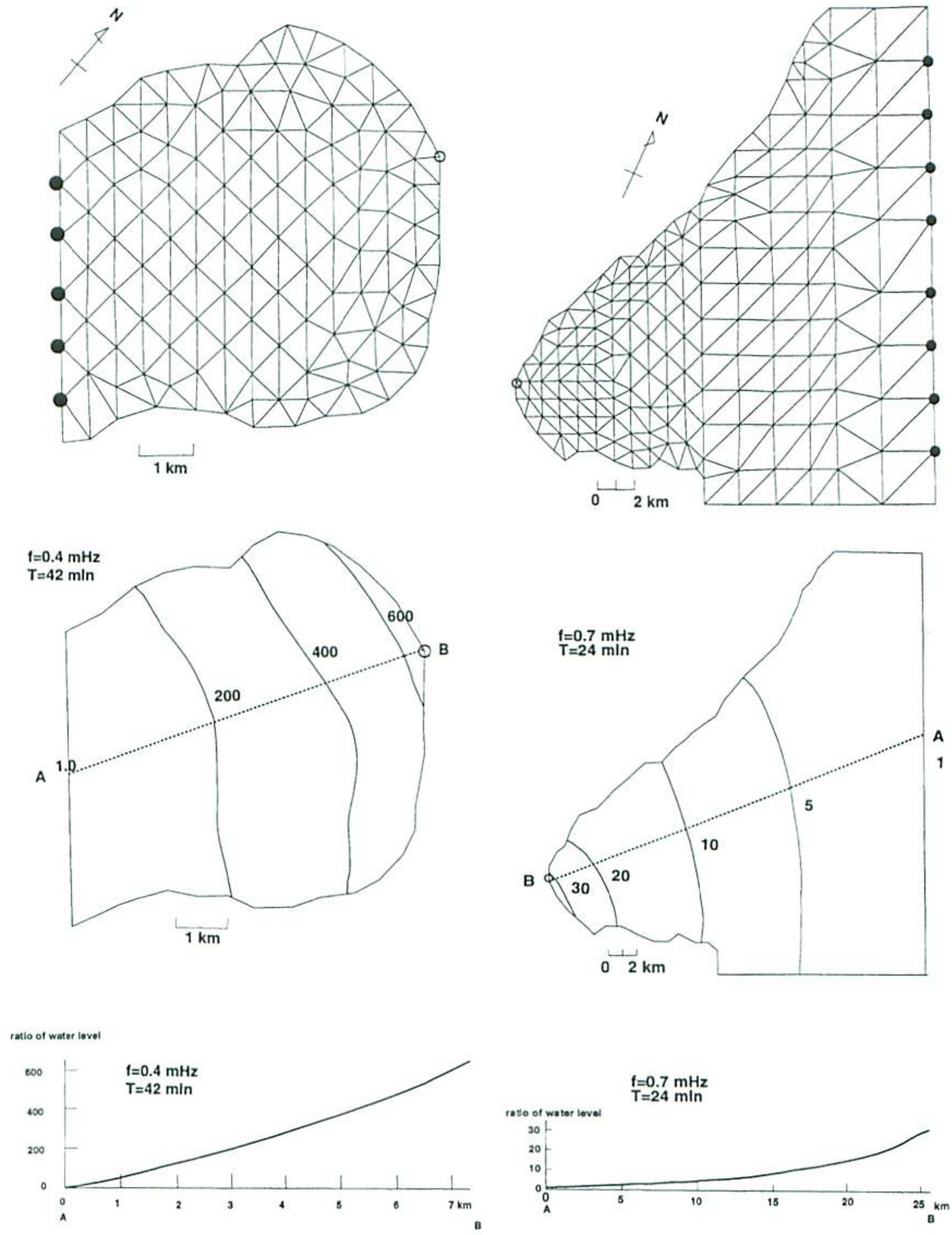

Figure 6 FEM models of Ryotsu (top left) and Mano (top right), amplitude distribution of the fundamental modes and the profile along the center lines A-B. A and B are pointed in the former figures.

period are attributed to a closed structure of the bay because of the shallow depth. The shallow sea bottom contributes to the closed structure in spite of the wide mouth.

At Ryotsu bay most predominant periods of 13,14, 22 and 52 minutes were observed. Among them the predominant period of 22 minutes was isolated and is nearest to 19 minutes in predominant periods of first case. In the two tsunamis the same predominant period of 24 minutes was observed. In the 1964 Niigata earthquake tsu-

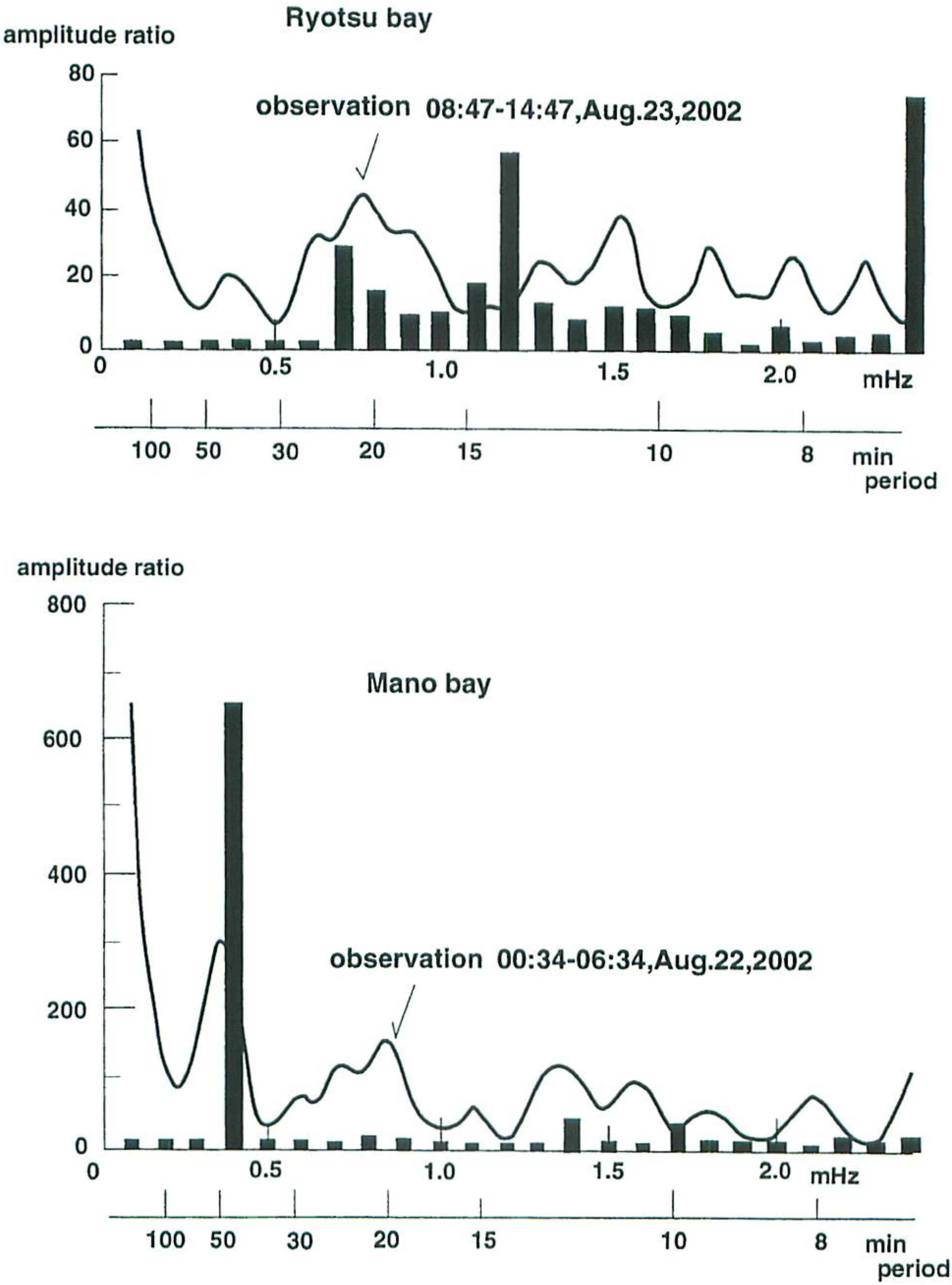

Figure 7 Comparisons of the observed spectra (solid lines) with frequency responses (bars) computed from the FEM models. Ordinate axis is arbitrary. Top for Ryotsu bay and bottom for Mano bay.

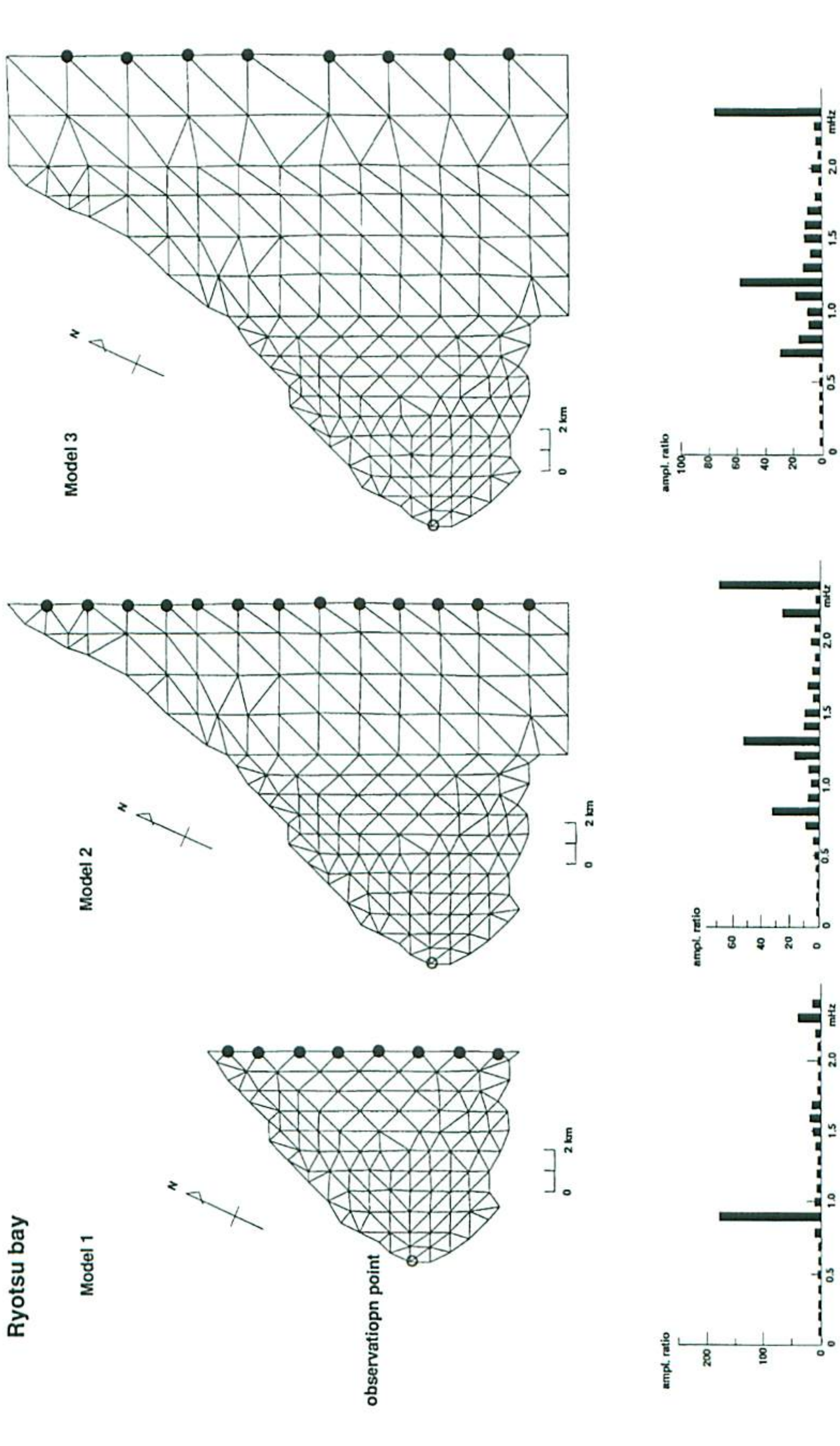

Figure 8 Variations of response at the observation point calculated from model 1, 2(Figure 6) and 3 for Ryotsu bay. The observation point is indicated with a open circle.

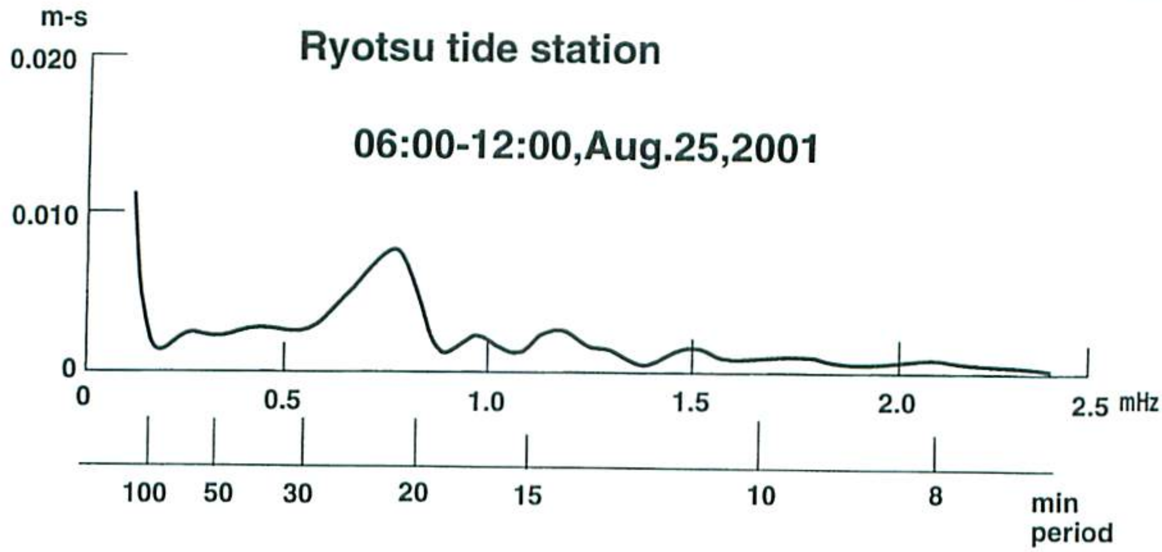

Figure 9 Typical example of the amplitude spectra observed at Ryotsu tide station in quiet sea condition on 25 August, 2001.

nami an averaged recurrence time of 21 minutes was recorded. From numerical computations to sinusoidal incidence amplification was largest in the period of 24 minutes. The wave profile shows a fundamental mode of the oscillation. Moreover, a stable spectral peak of 22 minutes was observed at the tide station in quiet sea conditions. Summarizing these facts we can conclude that the period of 22 minutes is a period of natural oscillation (seiche period). The previously predicted period of 22 minutes by Honda et al. (1908) is a good approximation of our value, 22 minutes, but that of 16.5 minutes by Nakagawa (1953) is smaller than it.

The difference of period in fundamental mode between Mano and Ryotsu bays is mainly attributed to that of sea depth in the bay. The former has the maximum depth of 30 m in the mouth but the latter has that of 500 m. This difference causes a reverse relation between size and period.

Conclusion

Long wave measurements at Mano and Ryotsu bays were conducted and the spectra were obtained. From the result it is concluded that the natural periods are 47 minutes at Mano bay and 22 minutes at Ryotsu bay. These spectral components are approximated as those of fundamental modes of the proper oscillations through FEM. Oscillation with these modes predominated in tsunamis.

Acknowledgements

Author thanks to port and airport office in Sado Island for providing tide gage data at Ryotsu tide station, and also thanks to Mrs. Mitsuko Abe for helping to take the sea level data.

References

Abe, K., An explanation of characteristic distribution of the tsunami maximum inundation heights observed at the small islands. Sci. Tsunami Hazards, 4,153-164, 1986

Abe, K., Frequency response of pressure type water level meter. Bulletin Nippon Dental Univ., General Education, No.30, 49-56, 2001.

Abe,K., Observations of selective amplification of tsunamis in bays to the source azimuth. Sci. Tsunami Hazards, 20, 102-117, 2002a.

Abe,K., Long wave measurements at bay-shaped coasts using a pressure gauge (I). Bulletin Nippon Dental Univ., General Education,No. 31, 43-52, 2002b.

Aida,I.,K.Kajiura,T.Hatori and T.Momoi, A tsunami accompanying the Niigata Earthquake of June 16,1964. Bull.Earthq.Res.Inst.,Tokyo Univ., 42, 741-780, 1964 (in Japanese).

Aida,I.T.Hatori, M.Koyama, H.Nagashima and K.Kajiura, Long-period waves in the vicinity of Onagawa bay(I)-Field measurements in Onagawa and Okachi bays. J. Oceanogr. Soc.Japan, 28, 27-39, 1972.

Honda, K., T.Terada, Y.Yoshida and D.Isitani, An investigation on the secondary undulations of oceanic tides. Jour.

Coll.Sci.Imp.Univ.Tokyo, 24, 1-113, 1908.

Kato,Y.,Z.Suzuki,K.Nakamura,A.Takagi,K.Emura,M.Ito and H.Ishida, The Chile tsunami of 1960 observed along the Sanriku coast of Japan. Sci.Rep.Tohoku Univ., Ser.5, Geophys., 13, 107-125, 1961

Nakagawa, K., Tsunamis in Sado Island. Quarterly Journal of Seismology, 18, 37-40, 1953.

Nakamura, K. and H.Watanabe, Nakamura, K. and H. Watanabe, Tsunami forerunner observed in case of the Chile Tsunami of 1960, Report on the Chilean Tsunami, edited by Field Investigation Committee for the Chilean Tsunami, 82-99, 1961

Nakano, M. and S.Unoki, On the seiches (the secondary undulations of tides) along the coasts of Japan. Records of Oceanographic Works in Japan, Special Number 6, 169-214, 1962.

Omori,F., Tsunamis in Japan. Publication of Earthquake Investigation Committee, 34, 5-80, 1900 (in Japanese).

Takahashi, R., Seiches and surface waves in Ofunato bay and two other bays. Bull.Earthq.Res.Inst. Univ. Tokyo, Suppl.I, 198-217, 1934.